Mini Review: Potential Utilization of Cassava Peel Waste as Raw Material for Bio Briquettes Production in Indonesia

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Abstract. Bio-briquettes have the potential to be produced in Indonesia, due to the availability of raw materials and the opportunities for domestic and export markets. Production of bio-briquettes can be strengthened through technology trials in the form of pilot projects and supported by regulations related to the production and management of renewable energy. Based on the results of the study, it is known that bio-briquette products made from cassava peel waste that can meet Indonesian national standards are those that use a composition of 80 % cassava peel charcoal and 20 % adhesive. Mixing with other agro-industrial waste will have an impact on product characteristics, including calorific value, water content, ash content, and volatile matter. To encourage the development of bio-briquettes from cassava peel waste, the government needs encouragement from strong regulations in funding technology research related to increasing energy efficiency, providing adequate energy infrastructure, and modeling competitive energy market prices.

Keywords: Bioenergy, clean energy, environmentally friendly, renewable energy, waste utilization.

1 Introduction

Bio briquette technology has been known since the 1980s, Until now there have been many developments related to production technology and its utilization [1]. The use of bio-briquettes in Indonesia is very low compared to other energy sources. On the other hand, Indonesia is able to export bio-briquette products made from coconut shells to Europe as much as 55 244 t yr^{-1} [2].

The problem was found, namely the scarcity of coconut shell raw materials when there was a high demand for bio-briquettes. Especially when conditions in Europe are currently

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experiencing an energy crisis, so they are forced to use alternative fuel sources, namely bio-briquettes [3].

Indonesia is not ready to face foreign market demand for bio-briquettes, which has suddenly increased rapidly. This is because the bio-briquette production technology developed in Indonesia is only made from coconut shells. Whereas there are many other biomass that have the potential to be used as raw material for bio-briquettes [4, 5].

So far, research has been carried out on other biomass-based bio-briquettes such as tuber skin, fruit peel, straw, husks, plant stems, and leaf midribs. So that the data can be used as a reference for production development to the pilot project stage or on a larger scale to help increase the production capacity of bio-briquettes in Indonesia.

One of the promising biomass to be used as raw material for bio-briquettes is cassava peel. Where it has been studied, it has quite good characteristics and a high calorific value. In addition, the availability of cassava peels is also not limited by seasons, so that the sustainability of production is more maintained than some other biomass.

This review aims to summarize updated technology and discuss evaluation of process operating conditions. In addition, it also provides insight into the potential use of cassava peel as a raw material for bio-briquette production. It is hoped that this review will be able to encourage product development so that it can meet standard requirements and the formation of a cassava peel-based bio-briquette industry.

2 Data and properties

To support this review, data and characteristics of cassava were collected from various sources. The latest references used include journal and proceeding articles indexed nationally and SJR. Statistical data obtained from national and foreign institutions. The data collected includes data on cassava production worldwide, data on cassava production in Indonesia, characteristics of cassava peels, and briquette product standards.

2.1 Cassava production world wide

Cassava production in the world in general has increased by about 3 % yr^{-1} [6]. The highest production is on the African continent with a portion of about 62 %. Asia produces 29 %, and the rest is in South America as much as 8 %. The world-wide cassava production data is shown in table 1.

Table 1. Top 10 Nations produce cassava [7]

No	Nation	Amount (t)
1	Nigeria	60 001 531
2	Democratic Republic of the Congo	41 014 256
3	Thailand	28 999 122
4	Ghana	21 811 661
5	Indonesia	18 302 000
6	Brazil	18 205 120
7	Vietnam	10 487 794
8	Angola	8 781 827
9	Cambodia	7 663 505
10	United Republic of Tanzania	7 549 879

2.2 Cassava production in Indonesia

The data on cassava production in Indonesia is shown in Table 2.

Table 2. Top 10 province produce cassava [8]

No	Province	Portion (%)
1	Lampung	34
2	Central Java	16
3	East Java	15
4	West Java	9
5	North Sumatera	7
6	Yogyakarta	4
7	East Nusa Tenggara	3
8	South Sulawesi	3
9	South Sumatera	1
10	West Sumatera	1

2.3 Cassava peel properties

Cassava contains impurities outside the external skin for 0.5 % to 2 %, internal skin for 8 % to 15 % and 80 % flesh [9].

The proximate composition of cassava peels is shown in Table 3.

Table 3. Proximate composition of cassava peels [10]

No	Parameter (unit)	Range
1	Protein (%)	2.06 to 4.55
2	Fat (%)	0.07 to 1.33
3	Fiber (%)	0.11 to 8.63
4	Ash (%)	0.07 to 4.05
5	Carbohydrate (%)	69.35 to 77.28
6	Moisture (%)	10.06 to 13.14

2.4 Briquette product standard

The requirements for briquettes to meet standards in Indonesia must follow SNI 01-6535-2000 as shown in Table 4.

Table 4. Indonesian national standard for charcoal briquette products [11]

No	Parameter (unit)	Value
1	Moisture content (%)	8
2	Ash content (%)	8
3	Volatile matter (%)	15
4	Calorific value (cal g^{-1})	5 000

The requirements for briquettes to meet standards in the EU must follow EN 1860-2:2005 and EN ISO 17225-3:2014, which are shown in Table 5.

Table 5. EU standard for charcoal briquette products [12–14]

No	Parameter (unit)	Value
1	Moisture content (%)	max. 6
2	Ash content (%)	max. 18
3	Fixed carbon (%)	min. 60
4	Calorific value (cal g^{-1})	3 500 to 3 700

3 Potency and obstacle of cassava peel waste utilization

Utilization of cassava peel waste has not been widely carried out. Cassava peels are generally found in traditional market trash cans, in the cassava chips and powder processing industry, and a small part in the derivative industry. Because of this, cassava peel waste is considered worthless and is disposed of directly at the municipal waste disposal site, without any treatment being mixed with other types of waste.

When cassava peel is used as a raw material for bio-briquette production, of course, it has potential and obstacles that must be sorted out in this review in order to get the best information on producing optimum bio-briquette products.

3.1 Potency of utilization

Currently, cassava peel waste is only disposed of in domestic waste in the market, cassava derivative factories, and small businesses in the food sector. In fact , based on the results of the analysis of cassava peel, it has a high calorific value. This makes cassava peel waste a potential use as bio-briquette, which is included in the waste-to-energy category.

Table 6. The top 10 provinces in Indonesia that use briquettes as fuel for cooking for household use [15]

No	Province	Percentage of fuel used for cooking					
		electric	**gas**	**Kerosene**	**briquette**	**wood**	**others**
1	Central Sulawesi	0.37	29.45	14.33	4.41	50.73	0.71
2	Riau	0.57	81.18	5.65	2.10	9.28	1.23
3	South East Sulawesi	0.58	43.80	17.72	1.48	35.88	0.54
4	Jambi	0.26	69.42	6.29	0.95	22.79	0.28
5	West Sulawesi	0.04	63.32	0.42	0.93	35.02	0.28
6	South Sulawesi	0.77	82.55	0.32	0.51	15.56	0.29
7	West Papua	0.44	1.59	58.05	0.31	39.01	0.61
8	East Kalimantan	1.04	93.71	1.09	0.27	3.10	0.79
9	Yogyakarta	1.11	65.12	0.24	0.26	26.16	7.12
10	Papua	0.27	0.80	31.46	0.14	67.04	0.29

Based on the data in Table 6, it is known that the consumption of briquettes in Indonesia is mostly found on the island of Sulawesi, namely Central Sulawesi, South East Sulawesi, West Sulawesi and South Sulawesi. On the island of Sumatra, there are two provinces that use briquettes, namely Riau, and Jambi. Other provinces that are included in the top 10 briquette users are West Papua, East Kalimantan, Yogyakarta, and Papua.

The use of wood in several provinces in Indonesia is relatively high, so it still contributes to global warming caused by deforestation. This must be minimized by promoting the use of alternative fuels, namely bio-briquettes originating from agro-industrial waste [16].

Table 7. List of European countries as briquette export destinations from Indonesia [2]

No	Nation	Amount (t)
1	Germany	9 213
2	Norway	24 030
3	Denmark	4 098
4	Netherlands	10 411
5	Belgium	6 799
6	Czech Republic	694

Indonesia exports briquettes as much as 7 % of the total consumption of briquettes in European Union countries. This shows that there is an opportunity to develop bio-briquette products from other biomass such as cassava peel. The energy crisis that occurs can provide its own opportunity to increase the acceptance of briquette products originating from Indonesia.

3.2 Obstacles

The initial problem with cassava peel waste is the difficulty of collecting the waste. This is because the location of the waste is in the traditional market trash which has been mixed with other domestic waste. Therefore, a waste sorting process is needed before being sent to collectors or alternative methods can use trash bins that are specially placed at each cassava seller's shop, so that cassava peel waste can be collected every day.

The problem that arises from handling the heat is the rotting of the cassava peel if it is stored in wet conditions for a long time. So the production process must run faster than other biomass such as coconut shell, which can last longer.

In addition, the next problem is the presence of impurities that must be separated from the skin using the washing method so that it will add steps to the production process so that the skin is cleaner and ready to be carbonized.

The absence of a cassava peel-based bio-briquette industry has resulted in the absence of a market and the unknown price of cassava peel waste. This will cause the cost of producing bio-briquettes from cassava peels to be unpredictable on an industrial scale. This problem can be solved by simulating the cost of collecting cassava peel waste so that the estimated price of the waste is obtained.

The absence of targets and plans for national renewable energy management has caused regulations to be implemented at every level. Poor coordination caused many aspects to be affected, including the aspect of providing inaccurate data, the lack of financial aspects for developing renewable energy for private investors, as well as aspects of providing technology and infrastructure to support private investment in the renewable energy sector. [17].

Focusing more on bio-briquette products that fall into the bio-energy category, the planned target is only 7 % of the fulfillment of national energy needs. Another problem is the fixing of renewable energy prices in Indonesia. This is due to several reasons, including because Indonesia is an archipelagic country, so there is an imbalance in the distribution of population and income between regions, causing uneven energy consumption [18].

Table 8. Bio briquette production operating conditions

No	Carbonization operating condition	Material composition	Result	Reference
1	T : 400 °C t : 45 min	n/a	C : 5 461 cal g^{-1} M : n/a A : n/a V : n/a	[9]
2	n/a	Coconut shell charcoal (78 %), cassava peel charcoal (19 %), adhesive (3 %)	C : 8 142 cal g^{-1} M : 7.04 % A : 4.37 % V : 2.01 %	[19]
3	T : n/a t : 4 h	Cassava peel charcoal (80 %) adhesive (20 %)	C : 5 126 cal g^{-1} M : 6.28 % A : 6.42 % V : n/a	[20]

Continued on the next page

Table 8. Continued

No	Carbonization operating condition	Material composition	Result	Reference
4	T : 400 °C t : n/a	Sengon wood sawdust charcoal (n/a), cassava peel charcoal (n/a) adhesive (20 %)	C : 1 802 cal g^{-1} M : 4.04 % A : 5.34 % V : n/a	[21]
5	T : n/a t : n/a	Cassava peel charcoal (95 %) adhesive (5 %)	C : 3 050 cal g^{-1} M : 10.76 % A : 4.40 % V : 83.06 %	[22]
6	T : n/a t : n/a	Cassava peel charcoal (80 %) adhesive (20 %)	C : 7 669 cal g^{-1} M : 10.50 % A : 5.0 % V : 60.00 %	[23]
7	T : 800 °C t : 45 min	Cassava peel charcoal (70 %) adhesive (30 %)	C : 3 785 cal g^{-1} M : 0.38 % A : 0.84 % V : 20.74 %	[24]

Annotation : C is calorific value, M is moisture content, A is ash content, V is volatile matter, t is time, and T is temperature.

3.3 Bio-briquette production operation conditions

Based on the operating conditions data that has been studied previously, the optimum results obtained with the heating value parameters of 8 142 cal g^{-1}, moisture content 7.04 %, ash content 4.37 %, and volatile matter 2.01 %. This value was obtained from the unknown carbonation operating conditions, with the composition of coconut shell charcoal: 78 %, cassava peel charcoal 19 % and adhesive 3 %.

In these operating conditions, it does produce a high calorific value. But there is something that is not right, namely the use of coconut shell charcoal which causes a high calorific value, so that the utilization of cassava peel waste is very low and is not in line with the original goal especially the use of cassava peels as raw material for bio-briquettes.

The alternative choice that is closest to the optimum result with the calorific value variables is 5 126 cal g^{-1}, moisture content 6.28 %, ash content 6.42 %. This value is obtained from the operating conditions of unknown carbonation temperature, with the composition of cassava peel charcoal 80 % and adhesive 20 %.

A lot of previous research data does not show clear and complete operating conditions or results. Because it is difficult to ensure the optimum conditions due to the lack of data in previous research. Because of this, further research is needed to develop the latest known optimum data.

3.4 Optimum operation conditions

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3.5 Regulation review

Indonesia, as a country with a fairly large potential for energy resources, has constraints in the form of public access to energy which is still limited. This is due to the non-optimal energy industry, limited energy infrastructure, uneconomical energy prices and inefficient use of energy.

The causes of these problems include regulations that have not encouraged the use of renewable energy sources. For example, in government regulation number 79, which was released in 2014 regarding national energy policies. The regulation explains that the use of national energy resources, especially the use of petroleum, is only for transportation and commercial purposes, which cannot be replaced with energy or other energy sources [25]. In this regulation, renewable energy has not been prioritized to increase its use capacity and has not supported the development of its industry.

This is in line with the presidential regulation of the Republic of Indonesia number 22 regarding the general national energy plan released in 2017. This regulation states that the potential for renewable energy in Indonesia is very large, but its utilization is still low. Information on the potential of renewable energy is obtained from surveys and modeling, while the utilization itself is still in the development plan stage [26].

To improve regulations, the expected targets must be set, namely increasing public access to energy, increasing energy supply security, adjusting energy prices to a more economical level, providing adequate energy infrastructure, increasing energy use efficiency.

Especially for renewable energy based on bio-briquettes, mitigation measures and regulatory adjustments must be made so that they can be implemented easily in the future. First, the need for support in conducting research so that bio-briquette technology is ready to be adapted by the industry. The support in question is grant funding and incentives for researchers who succeed in developing products with efficient technology [27].

The next step is to calculate the price of renewable energy through modeling and comparative studies with countries that have already used these energy sources commercially. Furthermore, regulations are needed that make it easier to provide infrastructure related to the renewable energy industry, as well as regulations that can maintain the security of the supply of renewable energy raw materials.

4 Conclusions

Indonesia is the fifth cassava-producing country in the world, where there is potential for cassava peel waste that has not been utilized, with an amount of about 8 % to 12 % of its total mass. It is an interesting challenge to convert this waste into renewable energy in the form of bio-briquettes.

There is little potential for the domestic market, but currently Indonesia has a share of the bio-briquette market of 7 % of the total consumption of briquettes in European Union countries. The energy demand will continue to increase amid the conditions of the European Union, which is being affected by the energy crisis and must shift energy sources.

To increase the production of bio-briquettes, it is possible to utilize the potential of cassava peel waste as a supply of raw materials. This is due to the limited supply of coconut shells that have been used so far and there has even been a shortage of coconut shell raw materials. The problem with bio-briquettes made from cassava peel waste is not be supported by regulations related to renewable energy, which only targets 7 % of the fulfilment of national energy needs. Whereas the source of raw material for cassava peel waste is quite easy to find in three islands, namely Sumatera, Java and Sulawesi.

There should be a bio-briquette industry on these islands, but the problem of not being in line with regulations related to renewable energy has hampered the development of technology, markets, and industry. So it takes encouragement from the government to produce strong regulations on technology research funding related to increasing energy use efficiency, providing adequate energy infrastructure, and modeling competitive energy market prices.

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References

1. R. M. Singh, “History of Bio Briquetting,” 2008 [Online] From https://web.archive.org/web/20100714000840/http://www.bgrcnn.net/documents/History%20of%20Bio%20Briquetting.doc (2008) [Acessed on September 30, 2022]
2. J. Zahnen, P. Hirschberger, V. Haag, and T.L. Lewandrowski. *2020 Analysis of The EU Charcoal Market*. Berlin: WWF Germany (2020) https://www.openagrar.de/receive/openagrar_mods_00066143.
3. Kementrian Luar Negeri Republik Indonesia [Ministry of Foreign Affairs of the Republic of Indonesia], *Arang Batok Kelapa Indonesia yang Kualitasnya Mendunia [Indonesian Coconut Shell Charcoal with Global Quality]*, [Online] from https://kemlu.go.id/maputo/id/news/13455/arang-batok-kelapa-indonesia-yang-kualitasnya-mendunia (2018). [Accessed Sep 20th 2022] [in Bahasa Indonesia]
4. G. Patil, Indones. J. For. Res., **6**, 2: 133–139 (2019) https://doi.org/10.20886/ijfr.2019.6.2.133-139
5. E. Yandri, B. Novianto, F. Fridolini, R.H. Setyabudi, H. Wibowo, S.K. Wahono, et al., E3S Web Conf., **226,** 00015 (2021) https://doi.org/10.1051/e3sconf/202122600015
6. R. Howeler, and K.S. Fahmey, *Cassava Production and Utilization In Asia and Its Potential As A Bio-Fuel*. Paper presented at NexGen Bio Ethanol Conference (Bangkok, Thailand, April 22th to 24th 2008) https://www.researchgate.net/profile/Reinhardt-Howeler/publication/322160964_CASSAVA_PRODUCTION_AND_UTILIZATION_IN_ASIA_AND_ITS_POTENTIAL_AS_A_BIO-FUEL_1/links/5a49d6e7a6fdcce1971eba3f/CASSAVA-PRODUCTION-AND-UTILIZATION-IN-ASIA-AND-ITS-POTENTIAL-AS-A-BIO-FUEL-1.pdf
7. Food and Agriculture Organization, *Top 10 Country Production of Cassava*, [Online] from https://www.fao.org/faostat/en/#rankings/countries_by_commodity (2020) [Accessed Sep 19 th 2022]

8. Badan Pusat Statistik [Statistics Center], *Produksi Ubi Kayu Menurut Provinsi (ton) [Cassava Production by Province (tons)]*, [Online] from https://www.bps.go.id/linkTableDinamis/view/id/880 (2015) [Accessed Sep 19th 2022] [inBahasa Indonesia]
9. A. Firdaus, and B. Octavianus, IJES, **2**, 2: 007–013 (2021) https://doi.org/10.51630/ijes.v2i2.14
10. M.A. Otache, S.T. Ubwa, and A.K. Godwin, Asian j. phys. chem. sci., **3**, 4: 1–10 (2017) https://doi.org/10.9734/AJOPACS/2017/36502
11. Badan Standarisasi Nasional [National Bureau of Standarization], SNI 01-6235-2000 tentang Briket Arang Kayu, Jakarta: BSN (2000) p.8 [in Bahasa Indonesia] http://sispk.bsn.go.id/SNI/DetailSNI/5750
12. European Committee for Standardization, *EN 1860-2:2005 Appliances, solid fuels and firelighters for barbecueing - Part 2: Barbecue charcoal and barbecue charcoal briquettes. Requirements and test methods* (2005) p. 26 https://www.en-standard.eu/csn-en-1860-2-appliances-solid-fuels-and-firelighters-for-barbecueing-part-2-barbecue-charcoal-and-barbecue-charcoal-briquettes-requirements-and-test-methods/
13. ISO. *EN ISO 17225-3 Solid biofuels—fuel specifications and classes part 3: Graded wood briquettes*. Geneva (2014) https://www.iso.org/obp/ui/#iso:std:iso:17225:-3:ed-1:v1:en
14. E. Cesprini, R. Greco, V. Causin, T. Urso, R. Cavalli, and M. Zanetti, Eur. J. Wood Wood Prod., **79**: 1153–1162 (2021) https://doi.org/10.1007/s00107-021-01695-1
15. Badan Pusat Statistik [Statistic Center], *Persentase Rumah Tangga Menurut Provinsi dan Bahan Bakar Utama untuk Memasak Tahun 2001, 2007-2016 [Percentage of Households by Province and Main Fuel for Cooking 2001, 2007-2016]*. [Online] From https://www.bps.go.id/statictable/2014/09/10/1364/persentase-rumah-tangga-menurut-provinsi-dan-bahan-bakar-utama-untuk-memasak-tahun-2001-2007-2016.html (2016) [Accessed: Sep 19th 2022] [in Bahasa Indonesia]
16. P.A. Ekoube, E. Gnikam, O. Said, V.L. Ngansop, and B.V. Bot, E3S Web Conf., **354**, 03004 (2022) https://doi.org/10.1051/e3sconf/202235403004
17. V. P. Lestari, *Permasalahan dan Tantangan Program Peningkatan Kontribusi Energi Baru dan Terbarukan dalam Bauran Energi Nasional [Problems and Challenges of the New and Renewable Energy Contribution Improvement Program in the National Energy Mix]* [Online] From https://123dok.com/document/z1d7d778-ringkasan-permasalahan-tatangan-program-peningkatan-kontribusi-terbarukan-nasional.html (2021) [Acessed on September 30, 2022] [inBahasa Indonesia]
18. Badan Pemeriksa Keuangan, *Laporan Hasil Pemeriksaan Kinerja atas Efektivitas Program Peningkatan Kontribusi Energi Baru Terbarukan dalam Bauran Energi Nasional [Report on the Results of a Performance Examination on the Effectiveness of the New Renewable Energy Contribution Improvement Program in the National Energy Mix]* [Online] From https://123dok.com/document/z1d7d778-ringkasan-permasalahan-tatangan-program-peningkatan-kontribusi-terbarukan-nasional.html (2020) [Acessed on September 30, 2022][inBahasa Indonesia]
19. R. Ropiudin, and K. Syska, Journal of Agricultural and Biosystem Engineering Research (JABER), **3**, 2: 19–39 (2022) [in Bahasa Indonesia] https://doi.org/10.20884/1.jaber.2022.3.1.6588
20. F.E. Hirniah, *Analisis Energi dalam Pembuatan Briket Arang dari Kulit Singkong dengan Tepung Tapioka Sebagai Perekat [Energy Analysis in Making Charcoal Briquettes from Cassava Peels with Tapioca Starch as an Adhesive]* [undergraduate Thesis] Teknik Pertanian, Universitas Jember (2020) [in Bahasa Indonesia] http://repository.unej.ac.id/handle/123456789/102242

21. F.T. Aprillia, *Pemanfaatan Limbah Serbuk Gergaji Kayu Sengon (Albizia Chinensis) Dan Perekat Kulit Singkong Dalam Pembuatan Briket [Utilization of Sawdust of Sengon Wood (Albizia Chinensis) and Cassava Peel Adhesive in the Making of Briquettes]* [Undergraduate thesis], Politeknik Negeri Jember (2022) [in Bahasa Indonesia] https://sipora.polije.ac.id/id/eprint/16227
22. J.T. Oladeji, and O.R. Oyetunji, Int. J. Energy Technol. Policy, **3**, 7: 40–47 (2013) https://www.iiste.org/Journals/index.php/JETP/article/view/6870/6979
23. U.E. Terhider, and O.E. Ediba, Int. Res. J. Mod. Eng. Technol. Sci., **3,** 10: 736–742 (2021) https://www.irjmets.com/uploadedfiles/paper/volume_3/issue_10_october_2021/16715/final/fin_irjmets1634718431.pdf
24. L. Rumiyati, A. Irnanda, and Y. Hendronursito, SPEKTRA: Jurnal Fisika dan Aplikasinya, **3**, 1: 15–22 (2018) [in Bahasa Indonesia] http://journal.unj.ac.id/unj/index.php/spektra/article/view/4863
25. *Peraturan Pemerintah Republik Indonesia, Nomor 79 Tahun 2014 Tentang Kebijakan Energi Nasional. Indonesia [Government regulation of the republic of Indonesia, Number 79 of 2014 about National Energy Policy]*, (2014) p. 36 [in Bahasa Indonesia] https://jdih.esdm.go.id/peraturan/PP%20No.%2079%20Thn%202014.pdf
26. *Peraturan Presiden Republik Indonesia*, *Nomor 22 Tahun 2017 tentang Rencana Umum Energi Nasional [Regulation of the President of the Republic of Indonesia, Number 22 of 2017 about The National Energy General Plan]* (2017) p. 227 [in Bahasa Indonesia] https://jdih.esdm.go.id/peraturan/Perpres%2022%20Tahun%202017.pdf
27. Menteri Energi dan Sumber Daya Mineral, *Blueprint Pengelolaan Energi Nasional 2006–2025 [National Energy Management Blueprint 2006–2025]*, Jakarta (2006) [in Bahasa Indoensia] https://www.esdm.go.id/assets/media/content/Blueprint_PEN_tgl_10_Nop_2007.pdf